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STUDY OF CLOUD LIQUID WATER PATH AND TOTAL PRECIPITABLE WATER FROM IRS-P4/MSMR AND NUMERICAL WEATHER PREDICTION MODEL OUTPUT

S. DAS*, A.S.K.A.V. PRASAD RAO**, U. C. MOHANTY**, A. K. MITRA*, AND D. RAJAN*
* National Centre for Medium Range Weather Forecasting, New Delhi – 110 003, India
**Centre for Atmospheric Sciences, Indian Institute of Technology
New Delhi-110 016, India

ABSTRACT

A global weather analysis-forecast system is used to produce six hourly analysis of meteorological fields at roughly 150 km × 150 km resolution at the National Center for Medium Range Weather Forecast (NCMRWF). In this paper, we have studied the Total Precipitable Water Content (TPWC) and Cloud Liquid Water Path (CLWP) derived from the Indian Remote Sensing (IRS-P4) Satellite over the Indian Ocean region in relation to operational numerical weather prediction (NWP) model analysis and short-range forecasts. An objective analysis was carried out by introducing the observations of CLWP, TPWC and their values (six hour forecasts) from the T80 model as the first guess, for a 20 days period of August 1999 using the standard Cressman's technique. The reanalysis could capture the signature of TPWC and CLWP data from IRS-P4 satellite. In general the observed values of TPWC and CLWP from IRS-P4 have a positive bias compared to NCMRWF analysis over the region where the satellite passed. The CLWP values have been compared with Special Sensor Microwave/Imager (SSM/I) products from the Defense Meteorological Satellite Program (DMSP) satellites. Results indicate that the model derived CLWP values were within acceptable limits, whereas the observations from the Multi-channel Scanning Microwave Radiometer (MSMR) showed slightly larger values.

Introduction

The IRS-P4 Oceanic Satellite Programme (OCEANSAT) was launched in May 1999 for retrieval of geophysical parameters for meteorological applications in real time. The meteorological data from IRS-P4 is extremely useful for a data sparse region like the Indian Ocean. The

*Corresponding Author's email: mohanty@cas.iitd.ernet.in

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TPWC and CLWP from IRS-P4 are important moisture parameters. These are related to the moist physical processes in the tropical atmospheres. Proper representation of moisture information and cloud description in the initial analysis prepared by data assimilation plays a crucial role in determining the quality of forecast. Earlier the TPWC and CLWP were available over the global oceans only from SSM/I of the DMSP. Now it is also available from the present operational US satellites National Oceanic and Atmospheric Administration (NOAA) F13, F14, F15 and IRS-P4/ MSMR. Numerous studies have been carried out using these data from SSM/I in relation to the numerical model outputs (Liu *et al.*, 1992; Phalippou, 1996; Ferraro, *et al.,* 1996; Kar *et al.*, 2003). These studies bring out the usability of such data by the NWP community in general.

It is well known that convection and clouds are among the most important physical processes driving the tropical atmosphere. In the past, some studies have been made to estimate cloud liquid water content in the tropical atmosphere using NWP models. However, the lack of observational data in particular, over the tropical Indian Ocean has limited the scope of understanding the tropical weather systems and their simulation by numerical models. Cloud processes are much more complicated owing to their scales of existence over space and time that is much smaller than the large-scale systems. Thus, it is important that appropriate satellite data sets be collected for understanding cloud processes and their simulation by numerical models. Weng *et al.*, (1997) derived the CLWP climatology from the SSM/I and, studied the atmospheric intra-seasonal oscillations at 30 to 60 days periods.

At present TPWC and CLWP from SSM/I are used operationally by various operational NWP centre for data assimilation and forecasting. In this study the TPWC and CLWP data from IRS-P4 were studied with respect to the operational analysis of NCMRWF to bring out the information content in this new data. This will help us in deciding the usage of IRS-P4 data and also the data from future Indian satellites (Kalyanaraman, 1999).

Data and Method

The data assimilation system of NCMRWF uses 6 hour forecasts from its global T80/L18 model as first guess and then blends all other available data to produce analysis valid for 00, 06, 12 and 18 UTC daily. The only moisture information over the Indian ocean comes from coarse resolution TIROS Operational Vertical Sounder (TOVS) of NOAA and 6 hour forecast from the model (NCMRWF, 2001). Thus, the final analysis of the model may broadly represent large scale TPWC and CLWP over the Indian Ocean, and may not give finer details. The representation of moisture in NWP analysis particularly over the tropical region, is largely influenced by 6-hour forecast of the model. This analysis of TPWC is used as the first guess in a Cressman type objective analysis scheme with 4 scan radii centered around 1.5^0, which is same as the NWP model resolution. The TPWC and CLWP data at 75 km resolution from IRS-P4 is then used as observation points in the reanalysis by Cressman technique, where the first guess was updated by inserting the new observations of TPWC and CLWP. The RMSE of the new analysis with respect to the observation is 1.1 mm for TPWC. Gohil (1999), described the details of the data from IRS-P4. The IRS-P4 launched in May 1999 was in sun-synchronous orbit with two-days repetivity, crossing equator at noon and mid-night over the Indian region. It carried onboard a MSMR, which operates at frequencies of 6.6, 10.65, 18 and 21 GHz in vertical and horizontal polarizations. The TPWC and CLWP derived from 18 and 21 GHz channels were made available at 120, 75 and 50 km resolutions by the National Remote Sensing Agency (NRSA). We have used the data at 75 km resolution in our study. The maximum possible value of TPWC from IRS-P4 over the tropical region is 80 mm and the theoretical retrieval accuracy in tropics is 1.56 mm (Gohil *et al.*, 2000). In this study all the data with good quality flag was used.

The CLWP from IRS-P4 provided by the NRSA have been analyzed and compared with the values obtained from the NCMRWF global model having a Relaxed Arakawa-Schubert (RAS) convection scheme (Moorthi and Suarez, 1992). The numerical model has been used to produce 6 hours forecast starting from 00 UTC initial conditions of 1-20 August 1999. The IRS-P4 data were analyzed using the Cressman type objective analysis technique similar to the TPWC.

Derivation of CLWP from the Model

NCMRWF uses a global spectral model originally adapted from National Center for Environmental Prediction. The horizontal resolution of the model is T80 and has 18 layers in the vertical. The initial condition for the model is provided from a global data assimilation system consisting of a procedure for quality control of data, the short-range (6 hour) model forecast as background field and the Spectral Statistical Interpolation method of analysis. A description of the NCMRWF model can be seen in Das (1996). The CLWP has been diagnosed using the RAS cumulus parameterization based on Moorthi and Suarez (1992). RAS assumes that all liquid water formed inside a cloud is carried to the top where it is detrained. The amount of detrained liquid water is computed using

$$l_{i,i} = \frac{1}{\eta}\left[q_k + \sum_{j=k}^{i}\left(\eta_{i,j-1/2} - \eta_{i,j+1/2}\right)q_j + \left(\eta_{i,i} - \eta_{i,i+1/2}\right)q_i\right] - q_i^*$$

where, l is the liquid water mixing ratio of the detraining air for the i^{th} cloud type, q_k is the water vapor mixing ratio at k^{th} level, η is the normalized cloud mass flux and q^* indicates the saturation vapor pressure. It is assumed that a fraction of this detrained water is precipitated and the rest is evaporated within the layer of detrainment. The RAS cumulus parameterization was extensively studied by Das *et al.* (1998) for a prognostic cloud microphysics parameterization scheme using observations collected from Tropical Ocean Global Atmosphere – Coupled Ocean Atmosphere Response Experiment (TOGA-COARE).

Results and Discussion

Analysis of TPWC from MSMR and NWP Analysis

In this study we have used the 06 UTC analysis from 1 to 20 August 1999. The IRS-P4 data over the Indian region was extracted, centered around 06 UTC with a time window of ± 2 hours. Fig. 1a shows a typical pass of IRS-P4 over the Indian Ocean around 06 UTC (± 2 hours) of 01 August 1999. Those data points are at 75 km resolution. Fig. 1b shows the comparison of the maximum values of TPWC over the Indian Ocean region from both NWP analysis and the IRS-P4 for a period of 20 days of August 1999. It shows a good agreement of the higher range of the TPWC from two different sources. This gives us a confidence regarding quality of the data (in terms of the range only). Fig. 2a shows an objective analysis of TPWC including the IRS-P4 data for 1-20 August 1999. Fig. 2b is the TPWC from NWP analysis of NCMRWF. Values more than 40 mm are seen north of 10^0 N in Fig. 2b. The values increase after including observations from the IRS-P4 in Fig. 2a. The TPWC values higher than 50 mm are shaded. Inclusion of the MSMR moisture data clearly enhances the TPWC values along the west coast and in the Bay of Bengal. It may be noted here that changes in the values are seen only over the oceanic region where data were included. Thus, only when we make a composite data set of the same meteorological parameter combining different satellites, the data set will be complete. Generally, the high values seen in Fig. 2a and 2b in the Bay of Bengal and the equatorial Indian Ocean are associated with areas of observed rain shown in Fig.

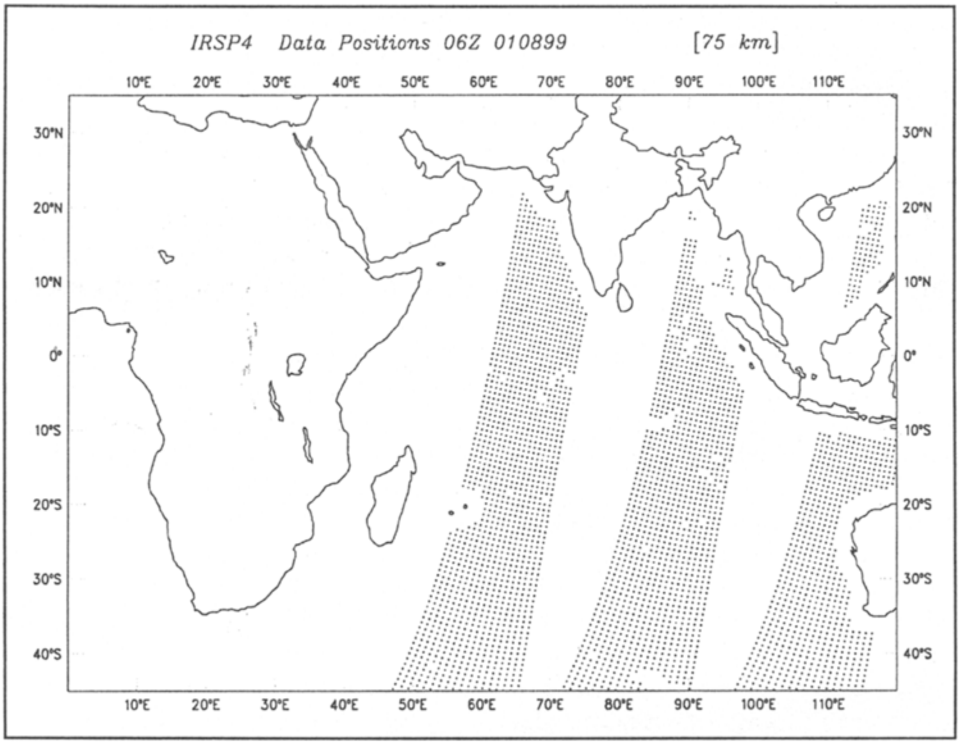

Fig. 1a: A sample pass of IRS-P4 showing data positions.

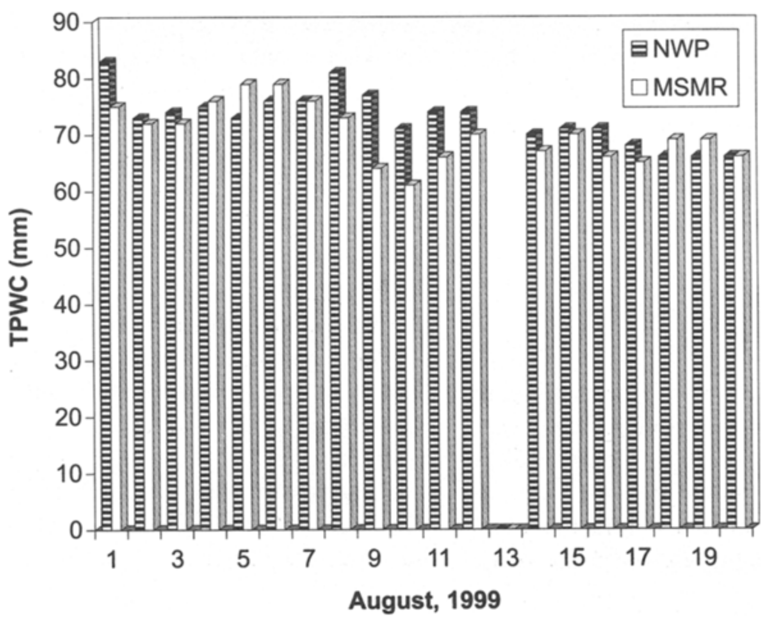

Fig. 1b: Maximum values of TPWC over Indian ocean from NWP and MSMR.

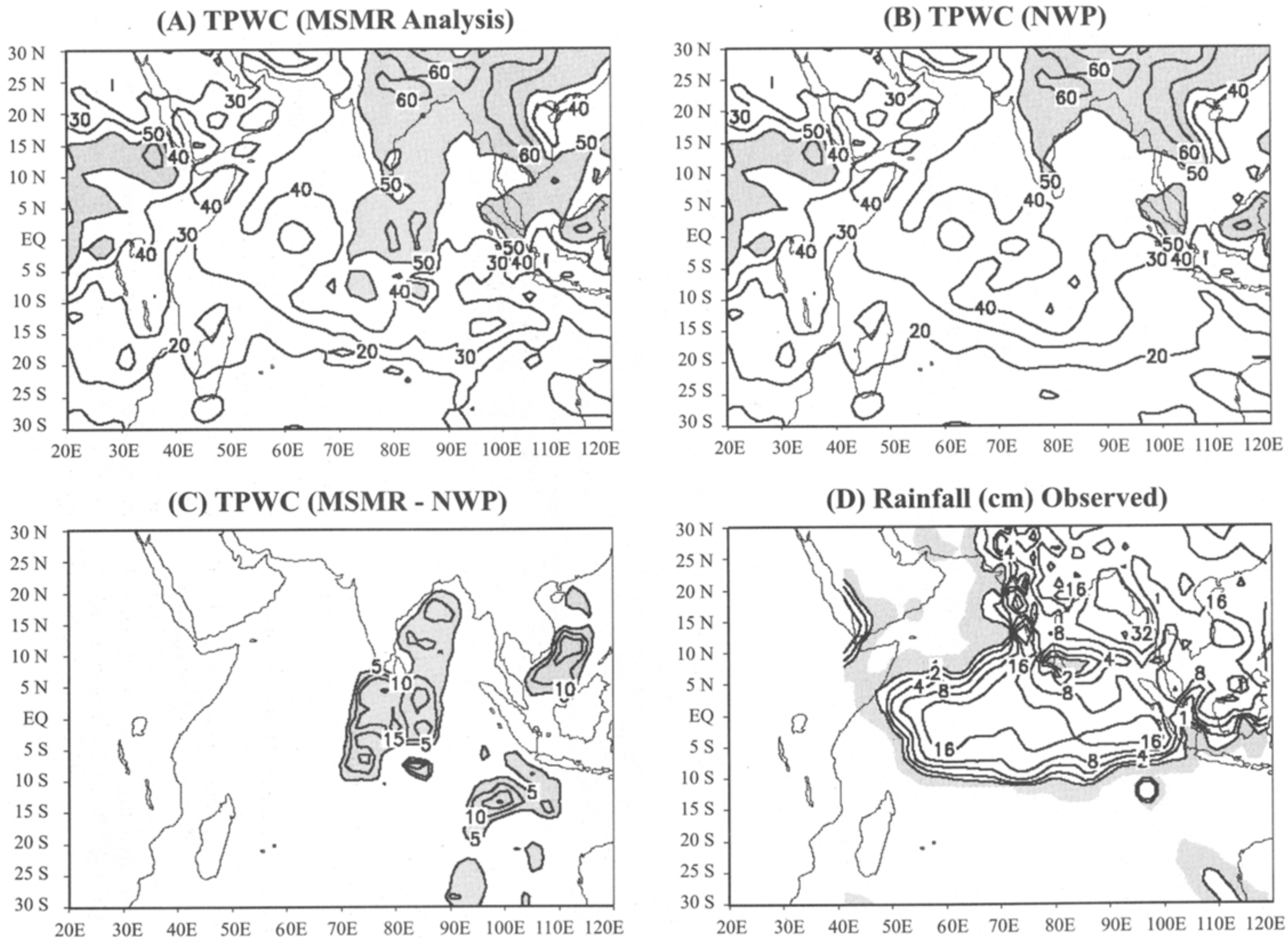

Fig. 2: TPWC in mm obtained from (a) MSMR using OI method (b) NWP (c) Difference of MSMR – NWP (d) Observed rainfall for the period 1-20 August, 1999.

2d for the same day. The observed rainfall is from a dataset (Mitra *et al.*, 1997) where the daily rainfall estimates from INSAT IR data and conventional rain gauge values are merged for the monsoon region. Fig. 2c clearly shows the impact of inclusion of the IRS-P4 observations in NWP analysis. The diagrams display differences reporting up to 25 mm. Most of the areas coinciding with the pass of IRS-P4 are having positive (shaded) values indicating systematically higher values of MSMR compared to the NWP product. This is also expected from individual observation points of MSMR, as the NWP produces smooth large-scale field. In a mean sense the inclusion of TPWC from IRS-P4 enhances the values of NWP analysis where high amount of rainfall occur as shown in Fig. 2d. The difference plot in Fig. 2c (positive areas are shaded with contour interval of 5 mm) conforms the positive bias of the satellite data over the satellite pass region. From this we conclude that the IRS-P4 values of TPWC are in general high compared to the NWP analysis of NCMRWF. If this data is included in the data assimilation, it should enhance the moisture analysis, which is important for better weather forecasts. The error statistics of this data in relation to model background forecast and the NWP analysis has to be established for a longer period for different oceanic regions over the globe. This will also be useful in the variational analysis schemes of the NWP centers. Inter-comparison of geophysical products including TPWC derived from MSMR, SSM/I and other sources have been done by many investigators, i.e., Ali *et al.* (2000), Verma *et al.* (2000). Aonashi and Shibata (1996) estimated the accuracy of TPWC from SSM/I to be 3.3 kg/m^2.

Analysis of CLWP from MSMR and Model

Figure 3 shows comparison of the CLWP derived from the MSMR and SSM/I for the month of August over the entire globe. The SSM/I values have been obtained from the DMSP and NOAA F13, F14 and F15 satellites. It has frequencies of 19.35, 22.235, 37.0 and 85.5 GHz with horizontal resolution of 25 km. In Fig. 3 the data points have been categorized in different ranges (i.e., less than 400, 400-600, 600-800, 800-1000 and above 1000 gm/m^2). Results show that about 80% of the MSMR data are within the acceptable range (less than 400 gm/m^2) as reported by Weng *et al.*, (1997) and numerical model outputs from the ECMWF (Mahfouf *et al.*, 1999), where as the SSM/I has only 40% data within the limit. Gohil (1999) has presented the accuracy of different retrieved parameters from the MSMR. It was indicated that in the tropics, the CLWP retrieved from MSMR ranged from 0-320 gm/m^2 with standard deviation of 280 gm/m^2. Therefore, unrealistic values (above 400 gm/m^2) of MSMR were filtered out while performing the objective analysis.

Fig. 4a shows the CLWP derived from MSMR using an optimum interpolation objective analysis scheme for 06 UTC of 1-20 August 1999. A standard Cressman technique with 4 scan radii around 1.5^0 was used similar to the TPWC analysis. The analyzed values of CLWP showed RMSE of 30 gm/m^2. The CLWP estimated by the RAS is displayed in Fig. 4b for the same period. The difference between the MSMR analyzed CLWP and the model-derived values is shown in the Fig. 4c. The corresponding observed rainfall based upon the estimates of satellite and rain gauge (Mitra *et al.*, 1997) are shown in the Fig. 4d. The diagrams indicate that, while the broad areas of the CLWP derived from the model and the MSMR match fairly well, their magnitudes differ considerably. The difference between the two estimates of the CLWP is as much as 200 gm m^{-2} (Fig. 4c). The difference between the model and the analysis is of the same order as that of the CLWP values themselves. In a qualitative sense, wherever the observations of CLWP are shown from the MSMR, the NWP model also shows the presence of CLWP. Rainfall is generally observed over the regions where high CLWP values are present except over the African continent. It may be noted that the rainfall derived by merging the satellite and rain gauge values are confined to the region between 40° - 120°E and 40°S – 40°N.

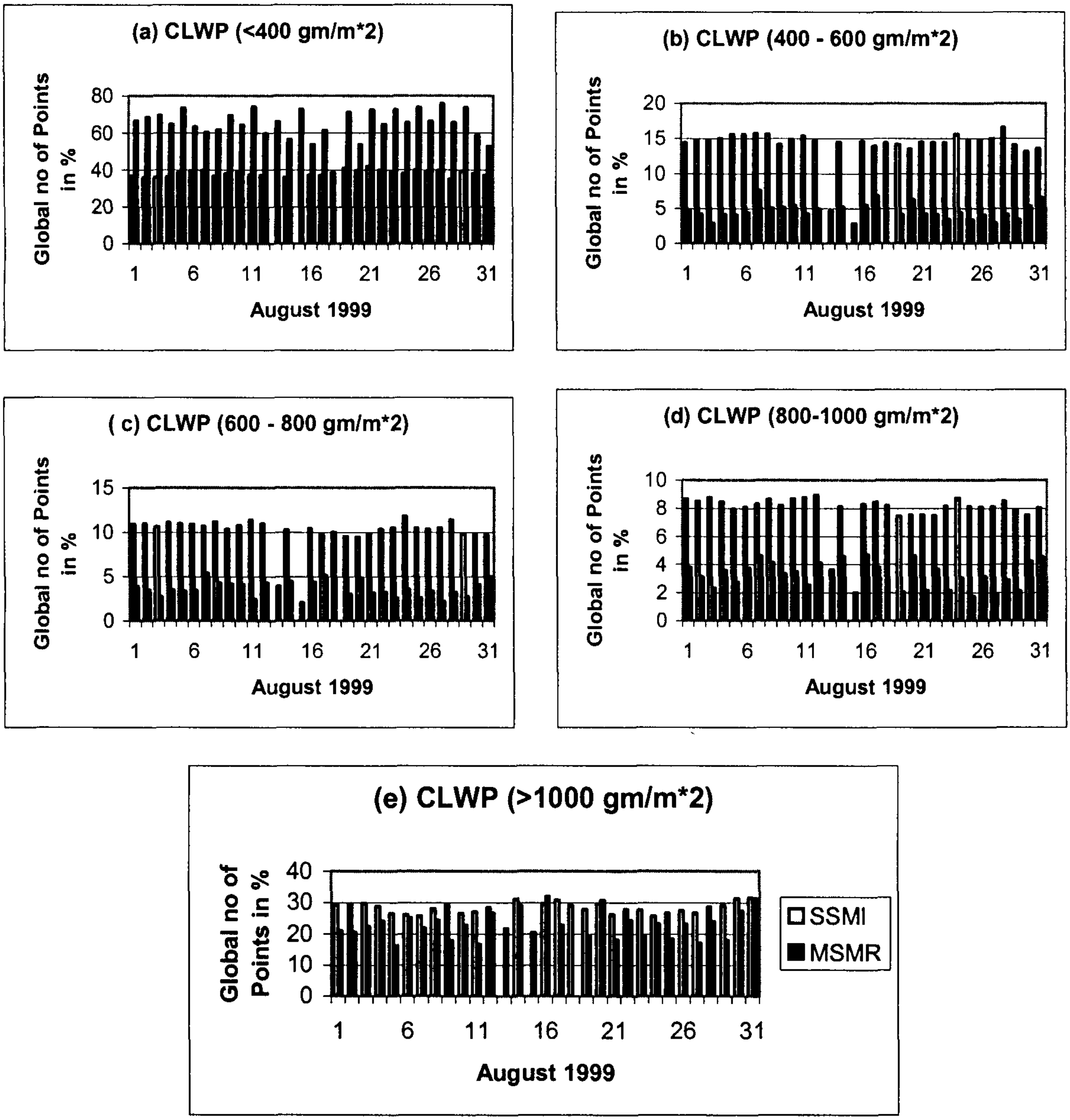

Fig. 3: Global number of points in % where the CLWP was (a) < 400, (b) 400-600, (c) 600-800, (d) 800-1000, (e) > 1000 in gm m^{-2} during August 1999.

Conclusion

The TPWC and CLWP observed from the MSMR (IRS-P4 OCEANSAT) has been analyzed using an objective analysis technique in which the total precipitable water content and cloud liquid water path obtained from a NWP model has been used as a first guess. Results showed good

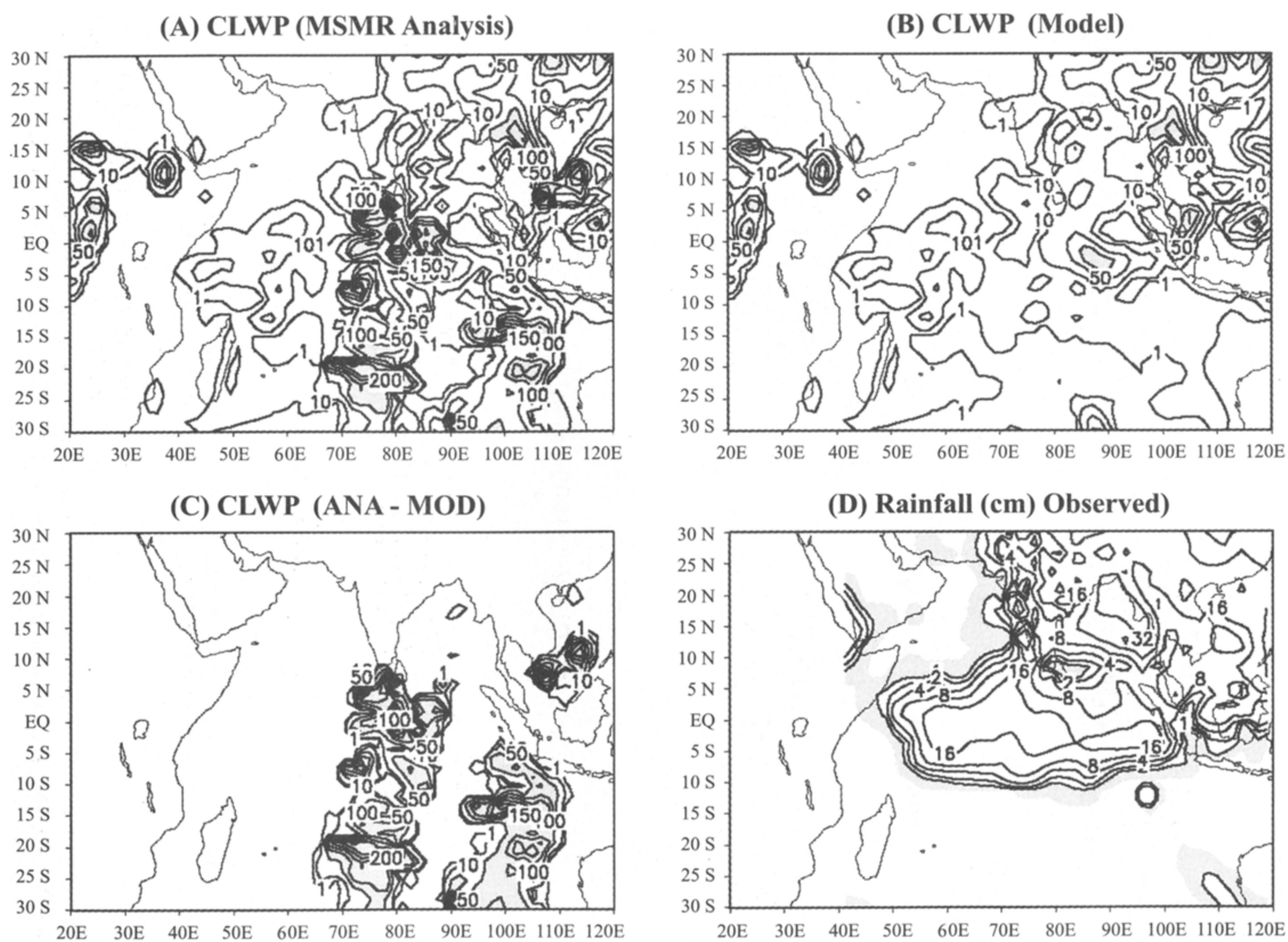

Fig. 4: As in Fig. 2 but for the Cloud liquid water path in gm m^{-2}.

agreement of the TPWC from two different sources and thus provide confidence regarding the quality of the data. The TPWC values indicated systematically higher values (positive bias) compared to NWP analysis. This is expected from individual observation points of MSMR, as the NWP product gives smooth large-scale field. Error statistics of this data in relation to model background forecast and the NWP analysis have to be established for a longer period for different oceanic regions over the globe. The statistical errors from the NWP analysis have to be compared with similar data from the SSM/I sources. Subsequently, the data can be included in the operational variational analysis schemes of NWP centres.

Study of CLWP indicated that, while the areas of observed CLWP matched broadly with those estimated by the model, their magnitude differed considerably. The differences are about 200 gm m^{-2}. Further studies are needed to confirm these results for different geographical regions over the globe.

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